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Modification of the Tide in the Canadian Arctic by an Ice Cover

G. Godin

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Marine Sciences and Information Directorate
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CONTENTS

ABSTRACT

Intuition suggests that the tide in the arctic should be modified by the presence of an ice cover; this paper presents a search for objective criteria to verify the reality of this phenomenon. Those tested are the admittance between the predicted tide at the local site and the observed water level or between the observed water level at an ice-free harbour and the local level, the mean time interval between the lunar transit and local occurrence of high or low water, the power spectrum of the observed levels in various frequency bands and the range (height difference between high and low water). None of these criteria gives an unequivocal answer but together they seem to indicate that the tide is apparently not modified at sites in good contact with the deep ocean. Sites removed from the open ocean by shallows or in deep recesses of water bodies like Hudson Bay are however affected; ranges appear higher during open water and the time of arrival of the tide is changed.

RÉSUMÉ

Il semble que la marée dans l'Arctique devrait être modifiée par la présence des glaces; ce présent mémoire consiste en une recherche de critères objectifs pour vérifier l'authenticité de ce phénomène. Ceux-ci sont: l'admittance entre la marée prédite au site de jaugeage et le niveau d'eau observé ou entre le niveau observé en un port non affecté par les glaces et le niveau d'eau au site étudié; l'intervalle moyen de temps entre le transit lunaire et l'occurrence de la haute ou basse mer, le spectre de puissance du niveau d'eau observé dans diverses bandes de fréquences et le marnage (différence de niveau entre la haute et basse mer). Auncun de ces critères ne donne de réponse non équivoque mais en leur ensemble ils semblent indiquer que la marée n'est pas affectée aux endroits qui sont en contact direct avec l'océan. Les endroits séparés de l'océan par des petits fonds ou dans des endroits éloignés, au fond de systèmes comme la Baie d'Hudson, semblent affectés toutefois; le marnage est plus fort durant l'absence de glaces et le temps d'arrivée de la marée est modifié.

It is my purpose to provide some detail concerning the influence of an ice-cover on the tide (Godin and Barber 1980). Russian workers (e.g. Zubov 1943; Laktionov 1960) were the first to suggest that an ice-cover modifies in some way the range and the time of occurrence of the tide and recent oceanographic measurements in the Beaufort Sea have shown that the tide at Tuktoyaktuk is quite different during ice-covered and ice-free seasons (Henry and Foreman 1977). Murty and Polavarapu (1978) wondered about the reality of the phenomenon. We wish to investigate if this effect is of a local nature or reflects a general modification of the tidal régime in the ice-covered regions of the ocean. Our conclusions, although not definitive, seem to indicate that the tide is not sensibly modified at most sites and that the ice effect is manifest only in regions remote from the main body of the ocean or separated from it by expanses of shallow water. The tendency to install tide gauges in sheltered locations, especially in the difficult arctic environment, tends to favor sites where the tide is modified locally. This, however, would not rule out the likelihood that the tide in the world ocean reflects in some subtle ways not only the formation and destruction of a seasonal ice-cover over parts of the arctic and antarctic, but also the existence of a perennial ice-cover.

DETECTION OF VARIABILITY IN THE TIDE

We measure the tide by observing the water level at a given site during as long a time as is practical. The tidal forces have known periodicities which we try to detect in the observations and the tidal components in the water level should have fixed amplitude and phase for these periods. To search for variability in the tide implies searching for significant fluctuations in the amplitudes and phases. Since the parameters are extracted from a set of observations over a given time interval, the choice of the time interval determines the scale of variability searched for. In our case, ice formation has an annual cycle and in some areas the transition from ice-free to ice-covered water spans a few weeks. As a consequence sets of constituents of the tide on a monthly basis should serve as an appropriate set of samples to check for the type of variability involved. Because of this requirement we are put immediately in a difficult position: the constituents of the tide cannot be adequately resolved over an interval of a month. It implies that a direct analytic approach to the problem does not appear the most promising. We must have recourse to indirect and perhaps less sharp methods to give more reliable information. Among the indirect methods at our disposal are:

a) The admittance method. We may compute admittance samples between a tidal signal with constant amplitude and phase and the water level to be investigated (Zetler et al. 1970; Godin 1977). An obvious choice for the constant tide signal is the predicted tide at the station investigated based on a one-year analysis; a possible drawback is that the constituents from a one-year analysis, based on least squares, will tend to reproduce some of the annual variability if it is regular enough in character. It follows that the admittance method used in this fashion may be quite blunt. An alternative is to use as input the constituents from a southern station where ice does not occur, e.g. Halifax.

b) Monthly samples of the power spectrum. In contrast to the samples from monthly harmonic analyses, monthly power spectrum estimates over bands of width 1 cycle/12 hours are stable and reliable. On the other hand, the monthly power in the tidal bands exhibits an annual variability which reflects changes in the tidal forces of the same frequency. Consequently the results of the power spectrum calculations must be interpreted carefully and with the support of additional data.

c) Ranges and lunitidal intervals. The range is the difference in level between high and low water and the lunitidal interval is the time elapsed between the transit of the moon at the meridian (and nadir) and the time of high water. These two parameters were used by the Russian workers in their pioneer investigations (e.g. Zubov 1943). Ranges vary appreciably, but about a rather stable mean value which has an annual cycle just like the power spectra. On the other hand, the lunitidal intervals tend to have fairly constant mean monthly values at a given station and any systematic change in them should be considered significant.

We shall use all the techniques to see if they converge toward the same conclusion; as we shall see none of their particular results can be considered overwhelmingly convincing, but when they all show the same trend we tend to believe that the tide signal is indeed modified.

STATIONS AND TIME INTERVALS SELECTED FOR THE INVESTIGATION

Figure 1 shows the Canadian Arctic and the permanent gauging sites. Shorter observations at Rae Point and Frobisher were also utilized because they were obtained from a submerged gauge and their quality was an order of magnitude higher. The permanent sites are:

Sachs Harbour	Lake Harbour
Tuktoyaktuk	Churchill
Cape Parry	Inoucjouac
Resolute	Cambridge Bay
Alert	Coral Harbour
Frobisher	

There exists a fair amount of reliable data for Tuktoyaktuk, Cape Parry, Resolute, Alert and Churchill. The tide observed at Sachs Harbour and Inoucjouac presents some difficulties independent of the quality of the record. Both stations are located in the vicinity of a semidiurnal point of amphidromy (Godin 1980): the position of the point varies appreciably in time and this manifests itself in a drift of the amplitude and phase of the semidiurnal tide signal. Since this signal is the strongest in the tidal semidiurnal band usually, the local tide at both sites is small and irregular. It is therefore difficult to separate the effect of the vagrancies of the node from that of the ice.

Fig. 1. Geographical position of the tidal stations whose record was investigated (from Godin and Barber 1980).

NATURE OF THE CALCULATIONS

We calculated the admittance between the predicted tide at a given station using a set of constituents based on a one year analysis of the same data. In the case of Inoucjouac and Sachs Harbour such a calculation seemed doomed from the start because of the obvious irregularity in the tidal signal, part of which had obviously nothing to do with a seasonal change. We therefore calculated for these two stations the admittance between the predicted tide at Halifax and the observed water level at the site. The tide at Halifax has little resemblance to the tide at either sites, but at least it is regular and we know that the harbour is ice-free in winter. The admittance was calculated over samples of a month's duration and calculated over bandwidths of 1 cycle/day which coincide with the tidal bands. We inspected the results and retained the values in the bands 0, 1, and 2.

To interpret the results of the admittance calculations, we note that if the observed tide did not change throughout the year, the value of the calculated sample admittances should be (1,0°) where the first number gives its amplitude, the second its phase, within the limits of confidence of the calculations. Any value of the admittance significantly different from (1,0°)

would indicate that the tide for that specific month differed from the mean tide for some reason or another.

Such an interpretation cannot hold for Inoucjouac or Sachs Harbour where we could not use the local constituents because of the hopeless nature of the local signal. There, in the semidiurnal band, we used the calculated admittance to infer the local temporary value of the constituent from the M_2 value at Halifax, which is 62.8 cm 234.8°; this gives an idea of the range of variability of the local semidiurnal signal during the year.

The admittance calculations also give as a by-product the value of the power spectrum over the bandwidths chosen; we present under the form of graphs the results for the semidiurnal band. If the yearly profile of the power spectrum values shows marked deformation during the ice-free months there is good reason to believe that the local tide is different during this season. Figure 2 shows the calculated daily values of the power spectrum for Tuktoyaktuk in a perspective diagram for two consecutive years of observations and indicates quite plainly that there is a profound change in the signal reaching Tuktoyaktuk during the ice-free season. Range and lunitidal calculations also give monthly samples of the mean range and time interval between lunar transit and high water. Ranges are highly correlated with the power spectra, especially the values in the semidiurnal band, and lunitidal intervals, although slightly dependent on the range tend to have fairly constant mean monthly values in general. If the values calculated show noticeably enhanced ranges during the ice-free months and significantly different lunitidal intervals, one could also conclude that this has to do with the removal of ice. If all these changes occur simultaneously for the same station, we feel that this is sufficient evidence to conclude that the local tide is affected by an ice cover.

ADMITTANCE CALCULATIONS

Most of the admittance calculations are not shown because their results were mainly negative, i.e. for most of the stations the sample values fell on (1,0°) within their limits of confidence. The only station where values of the admittance were markedly different from (1,0°) was Tuktoyaktuk, but with the low level of coherence present, they could barely be considered statistically significant. The calculated values of the admittance samples for Alert and Tuktoyaktuk during the years indicated are shown in Table 1.

We have presented the results for Alert and Tuktoyaktuk because they represent the extremes in the calculated values of the admittance. At Alert we get a consistently high degree of coherence and the calculated values of the admittance agree with the hypothesis (1,0°). At first sight then it seems that the tide is very regular at Alert and does not change appreciably throughout the year. At Tuktoyaktuk, the degree of coherence is much lower (as far as tides are concerned) and it is particularly poor between August and November. The amplitude differs significantly from 1 in July and the phase (negative, indicating the tide being earlier during this particular month) is out by some 26 min. Except for August, the other admittance samples are consistent with an hypothesis of (1,0°); an error of ± 5 min in phase is not considered significant because this is the usual limit of

Table 1. Monthly admittance samples for Alert and Tuktoyaktuk using as input the predicted tide from a one year analysis and the observed water level as output. Semidiurnal band (2 cycles/day) at 90% confidence.

	Alert 1973			Tuktoyaktuk 1963		
Month	Coherence	Amplitude	Phase deg.	Coherence	Amplitude	Phase deg.
January	.9990	1.00±.01	0±1	.9792	.9 ±.1	4±3
February	.9996	1.00±.01	.8±.5	.9925	.95±.04	7±2
March	.9996	1.00±.01	.8±.5	.9944	.96±.03	6±2
April	.9995	1.01±.01	.2±.5	.9853	.97±.05	3±3
May	.9995	1.00±.01	.4±.5	.9880	.98±.04	1±3
June	.9994	1.00±.01	.2±.6	.9817	1.03±.05	0±3
July	.9991	1.01±.01	0±1	.9797	1.3 ±.1	-13±3
August	.9993	1.00±.01	-1±1	.9284	1.0 ±.1	-12±6
September	.9994	.99±.01	0±1	.9666	1.1 ±.1	1±4
October	.9992	1.00±.01	-1±1	.9372	1.0 ±.1	-4±6
November	.9991	1.00±.01	0±1	.9717	.9 ±.1	0±4
December	.9993	.99±.01	0±1	.9643	.9 ±.1	-1±4

Table 2. Monthly admittance samples for Cape Parry using as input the predicted tide from a one year analysis and the observed water level as output. Semidiurnal band (2 cycles/day) at 90% confidence. Year 1968.

Month	Coherence	Amplitude	Phase deg.	(Power spectrum) ft 2/cycle/hr
January	.9937	1.03±.03	-2±2	1.76
February	.9945	1.00±.03	0±2	1.75
March	.9951	.96±.03	3±2	1.80
April	.9975	.99±.02	-2±1	1.88
May	.9927	1.00±.03	0±2	1.93
June	.9938	1.00±.03	2±2	2.06
July	.9940	1.01±.03	3±2	2.45
August	.9969	1.01±.02	3±1	2.88
September	.9880	.99±.04	-1±3	2.92
October	.9940	1.04±.03	2±2	2.73
November	.9941	.99±.03	-1±2	2.06
December	.9962	.98±.02	0±1	1.73

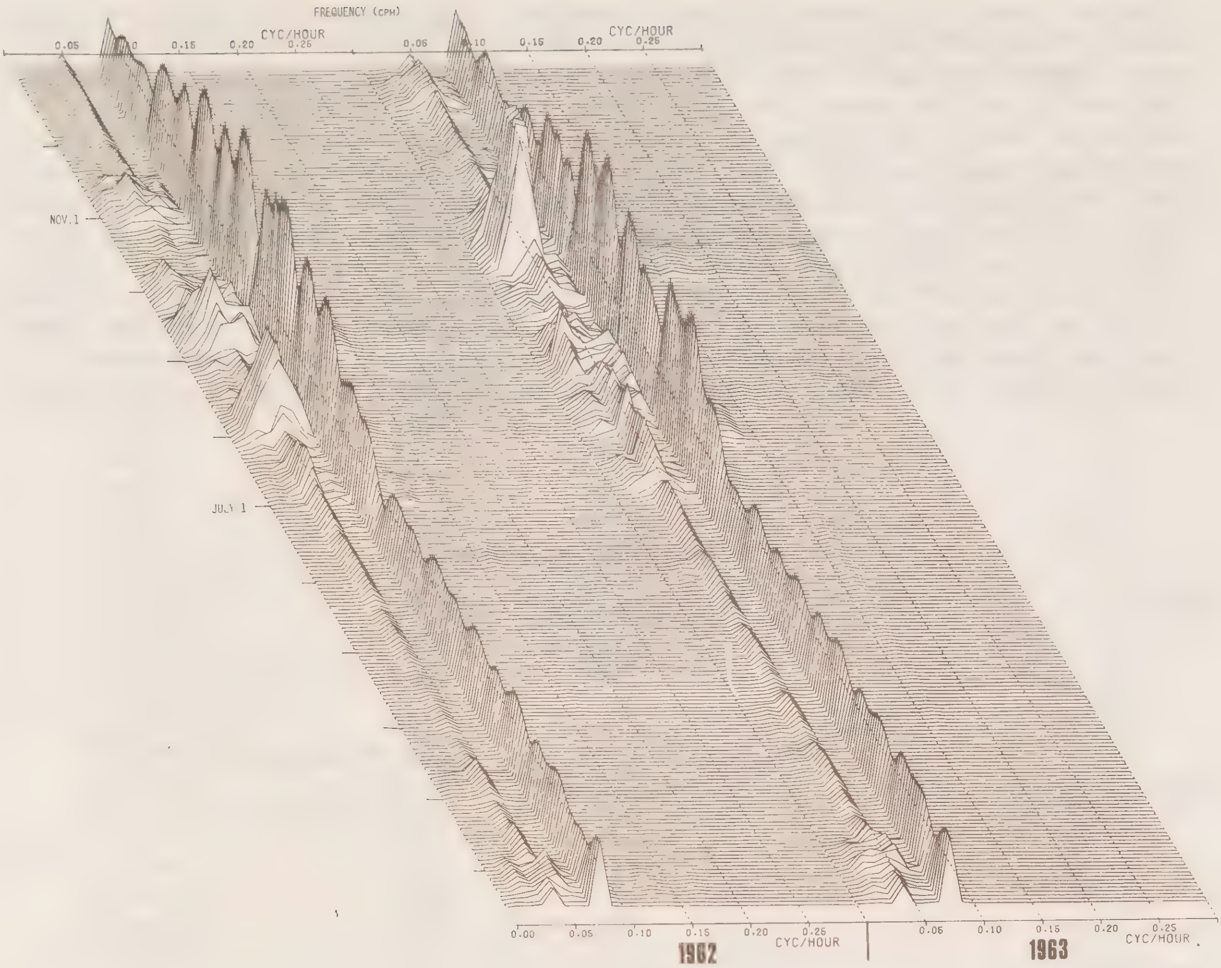

Fig. 2. Power spectra (ft^2/h) over 50 frequency bands (cph) in the observed hourly values of water level at Tuktoyaktuk for the years 1962 (left) and 1963 presented in the form of overlapping segments. Each segment comprises 15 days of data and each is advanced by 1.5 days from January 15 to December 31, i.e. from the bottom toward the top (from Godin and Barber 1980).

resolution in tide gauges. A look at Fig. 2 hints that the admittance estimates are overly optimistic and reflect the fact that the predicted tide models some of the annual variation seen in the diagram, with consequent dulling of the admittance values. The diagram indicates that the admittance values should be of the order of (1,0°) for the ice-covered months; in the table, we see that the amplitude increases gradually from .9 to 1.3 from January to July. Without doubt then the predicted tide reproduces some of the annual variability; this forces us to have recourse to other techniques, the power spectrum obviously being one.

To give an idea of the ambiguity of the results of the admittance calculations we present (Table 2) the calculated values for Cape Parry. The admittance has effective amplitude and phase of more or less (1,0°) but with more scatter than Alert. We give in addition the power spectrum which shows

a marked increase between July and November. The evidence of the power spectrum is not sufficient however to conclude that the tide is larger during these months because of the diminished presence of ice. We show for example the profile of the power spectrum in the semidiurnal band of the tide at Pointe au Père (Fig. 3), which should be minimally affected by ice: we see two annual peaks and note that the largest peak occurs during February-March when ice conditions are normally at their worst in the Gulf of St. Lawrence. These peaks reflect annual cycles in the tidal forces; they tend to be found around February-March and August-September. So at first sight, it is difficult to decide if the tide at Cape Parry exhibits an annual variation linked in any way to the presence of ice. More refined studies will indicate later that the range of the tide at Cape Parry increases slightly during open water but that any change in the time of arrival of the tide is undetectable.

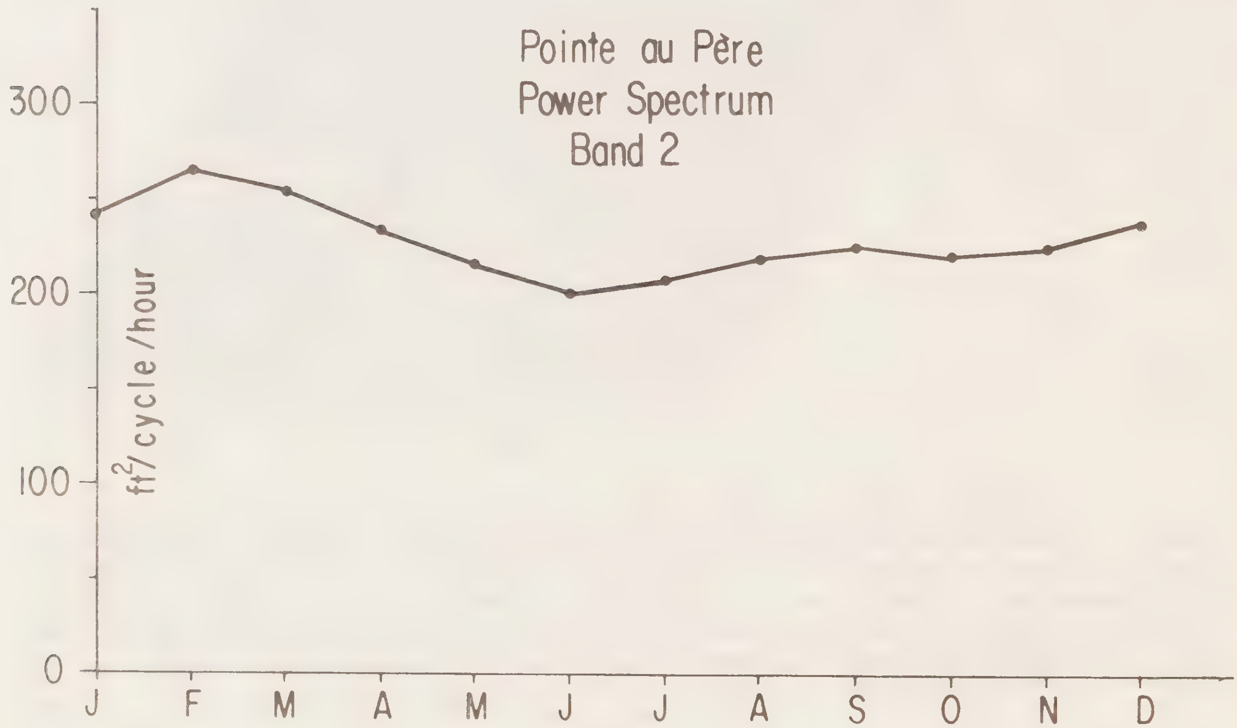

Fig. 3. Consecutive monthly values of the power spectrum in the semidiurnal band of the observed water levels at Point au Père, a southerly gauge station.

We show finally (Table 3) the calculated admittance samples in the semidiurnal band for Inoucjouac and Sachs Harbour using Halifax as input and see unambiguous changes in the character of the tide during the year. Figure 4a shows the amplitude and phase of the admittance between Halifax and Inoucjouac. For the two years of observations available, the amplitude turns abruptly between June and July while the phase exhibits a marked change between May

Table 3. Admittance calculations for Inoucjouac and Sachs Harbour using the predicted tide for Halifax (an ice-free harbour) as input for the semi-diurnal band (2 cycles/day).

Year	Month	Admittance with Halifax			Inoucjouac M_2 inferred from Halifax (62.8 cm 234.8°)	
		Coherence	Amplitude	Phase	Amplitude cm	Phase °
1970	January	.9809	.1825	79.4	11.5	314
	February	.9691	.1307	74.9	8.2	310
	March	.9374	.1130	79.8	6.9	315
	April	.9606	.1217	78.7	7.6	314
	May	.9536	.1130	91.5	7.1	326
	June	.9447	.1468	101.5	9.2	336
	July	.9707	.2273	106.8	14.3	342
	August	.9571	.2201	103.7	13.8	339
	September	.9157	.2042	105.0	12.8	340
	October	.9294	.2165	102.6	13.6	337
	November	.9758	.2321	93.9	14.6	329
	December(12 days)	.9657	.2315	86.9	14.5	322
1971	September	.9510	.2082	105.5	13.1	340
	October	.9374	.2067	100.7	13.0	336
	November	.9554	.2199	98.4	13.8	333
	December(23 days)	.8285	.1160	104.7	7.3	340
1973	September	.9628	.2228	101.9	14.0	337
	October	.9545	.2122	100.9	13.3	336
	November	.9677	.2267	92.2	14.2	327
	December	.9825	.2496	87.9	15.7	323
1974	January	.9758	.1816	81.2	11.4	316
	February	.9652	.1599	73.4	10.0	308
	March	.9737	.1582	69.6	9.9	304
	April	.9691	.1370	62.3	8.6	297
	May	.9528	.1261	78.6	7.9	313
	June	.9690	.1972	104.8	12.4	340
	July	.9722	.2226	105.4	14.0	340
	August	.9619	.2147	103.0	13.5	338
	September	.9578	.2149	96.4	13.5	331
	October	.9649	.2128	95.3	13.4	330
	November	.9790	.2381	92.6	15.0	327
	December	.9811	.2636	90.6	16.6	325

M_2 from a direct one year analysis for 1974
11.2 cm 330.1°
Z = +5

Table 3. (Cont.)

Year	Month	Sachs Harbour Admittance with Halifax Coherence	Amplitude	Phase	M_2 inferred from Halifax Amplitude cm	Phase °
1974	January	.9729	.0612	23.4	3.8	258
	February	.9912	.0579	26.1	3.6	261
	March	.9912	.0564	25.5	3.5	260
	April	.8812	.0499	-16.8	3.1	218 ?
	May	.9678	.0523	9.1	3.3	244

	August	.9591	.0814	21.8	5.1	257
	September	.9775	.0852	40.5	5.4	275
	October	.9784	.0791	25.8	5.0	261
	November	.9818	.0699	18.3	4.4	253
	December	.9917	.0597	22.6	3.7	257

M_2 from a direct one year analysis for 1974
4.7 cm 262.4°
$Z = +8$

and June. For 1974, the phase shift is of the order of 27° or nearly one hour in time and the amplitude shift, of the order of 60%. It is no wonder that a direct analysis of such a record fails to supply adequate estimates of the components in the semidiurnal band. The record for Sachs Harbour is more fragmentary (Fig. 4b). There is definitely a marked increase in amplitude after August with a decrease following later. The phase appears to increase during August-September. If we interpret the phase as reflecting the time of arrival of the semidiurnal tide, we see that the larger phase for the ice-free months at Inoucjouac and Sachs Harbour implies that the tide gets there *later* during the ice-free months which is opposite to what has been assumed in the Russian papers referred to above. We shall verify later that this is the case for other stations as well.

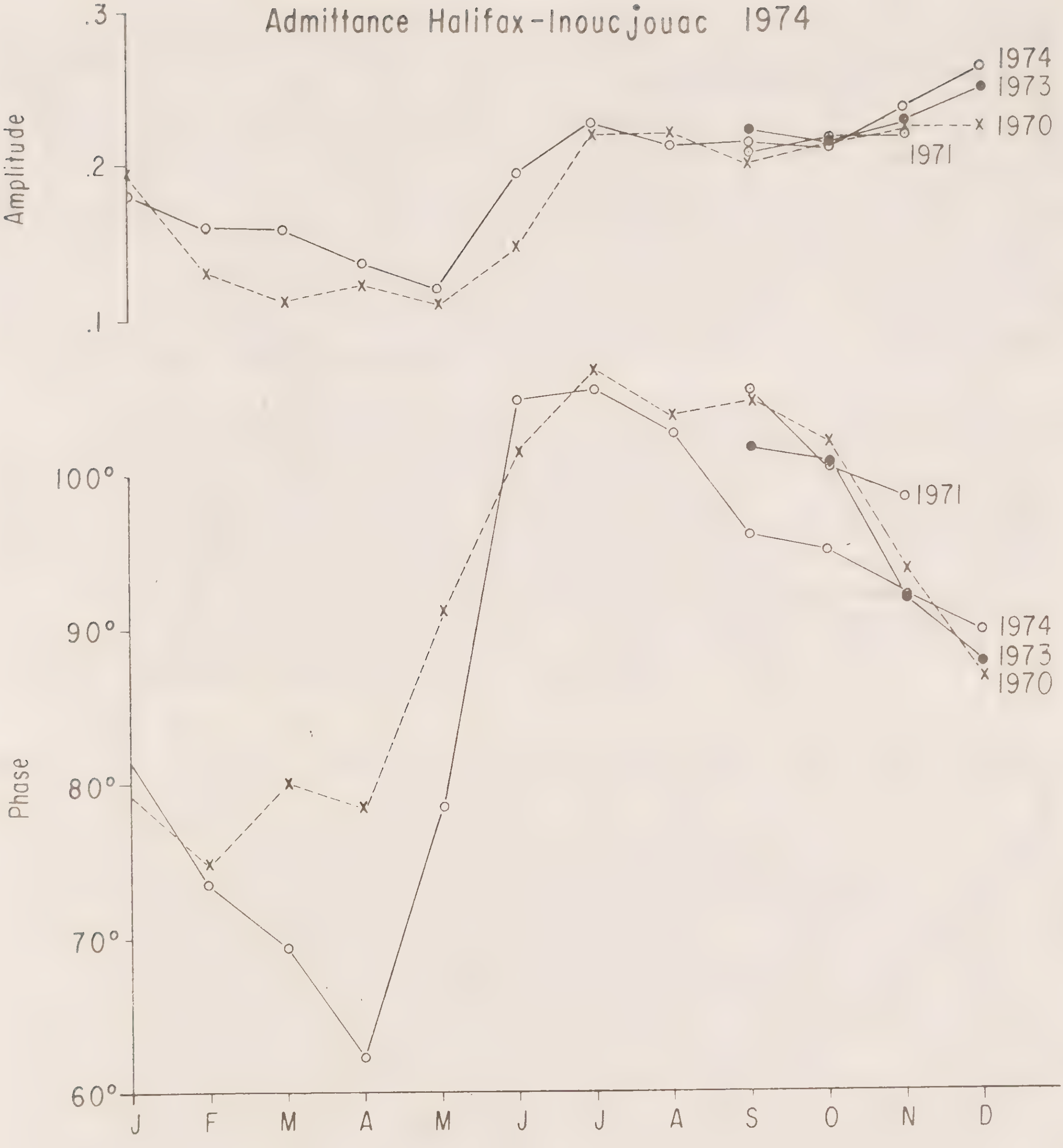

Fig. 4a. Computed admittance between the water levels at an ice-free station (Halifax) and two northerly stations lying in the vicinity of semidiurnal amphidromies. Inoucjouac: calculated admittance for various years and portions of years for monthly samples of data. The admittance has amplitude, shown in the upper panel, and phase, shown in the lower panel. An abrupt change is notable between April and June.

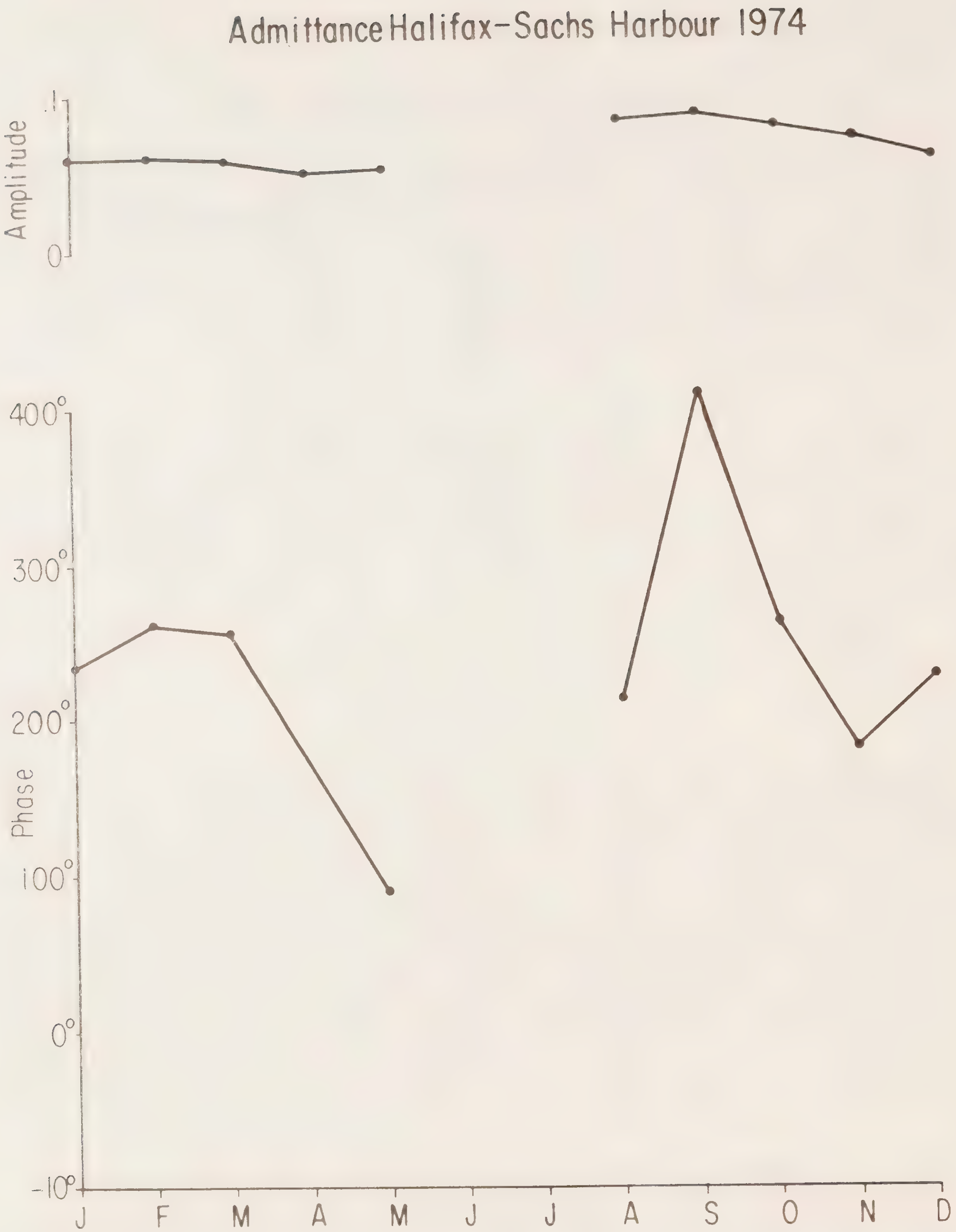

Fig. 4b. Computed admittance between the water levels at an ice-free station (Halifax) and two northerly stations lying in the vicinity of semidiurnal amphidromies. Sachs Harbour: the data are fragmentary but there appears to be a marked change in amplitude and phase between the two fragments.

CALCULATION OF POWER SPECTRA, RANGES AND LUNITIDAL INTERVALS

In order to firm up the admittance calculations we calculated the power spectrum of the records available for bandwidths of 1 cycle/12 hours which correspond to the major tidal bands. We also calculated the mean monthly range and mean lunitidal intervals. The results are presented in a series of graphs because no quantitave use has been made of the material. The variable which is most likely to exhibit marked changes in the character of the tide is the lunitidal interval because it should be fairly constant from month to month. Figure 5 shows the calculated mean monthly lunitidal intervals for the 12 months of the years for the stations listed at the outset. We show in the left panel the individual values obtained for specific years and in the right panel the average of those values. For some stations only one year was available or only a couple of months for additional years; for these only the sample values are shown.

The station exhibiting the most obvious variability is Tuktoyaktuk. The tide occurs at least 1½ hours earlier during July-August-September and it occurs the latest in May. Other stations also exhibit a marked seasonal change in the time of arrival of the tide: Cambridge Bay, Churchill and Coral Harbour where the tide occurs later during the open water months by something like 30 min. Lake Harbour and Frobisher exhibit no such variability and the time of arrival of the tide seems to be constant throughout the year. Resolute, Alert, Rae Point and Cape Parry exhibit somewhat variable lunitidal intervals if one excepts the value for August at Rae Point which covers less than a month but with no clear trends.

We show (Fig. 6) the power spectrum in band 0. There is appreciable energy in this band. The plots vary from station to station and exhibit no common trend except that peaks tend to occur during the winter months, reflecting probably the fact that storms and consequent persistent perturbations in the mean level are more likely to occur during this season. Figure 7 shows the power in the diurnal band which is created mainly by the diurnal tide. We notice at Resolute, Alert, Frobisher and Rae Point a regular annual cycle which obviously has nothing to do with the ice cycle but with that of the tidal forces. We find the same cycle in Cape Parry and Lake Harbour but with some distortion. On the other hand Cambridge Bay, Coral Harbour and Churchill exhibit a net increase in power during the ice-free months while Tuktoyaktuk exhibits an unequivocal peak during July-August. Figure 8 shows the power spectrum in the semidiurnal band where most of the tidal energy is concentrated along with the mean monthly range which tends to be highly correlated with the power in this band. The scale of the power spectra varies from station to station; for the range it is 1 foot with the exception of Lake Harbour and Frobisher where it is 10 feet. The range tends to reflect the power spectrum as already said and we notice a seasonal change in Churchill, Cambridge Bay, Coral Harbour and Tuktoyaktuk.

We give in Tables 4 and 5 a summary of the conclusions which can be reached from the graphs and the admittance calculations for the various stations investigated.

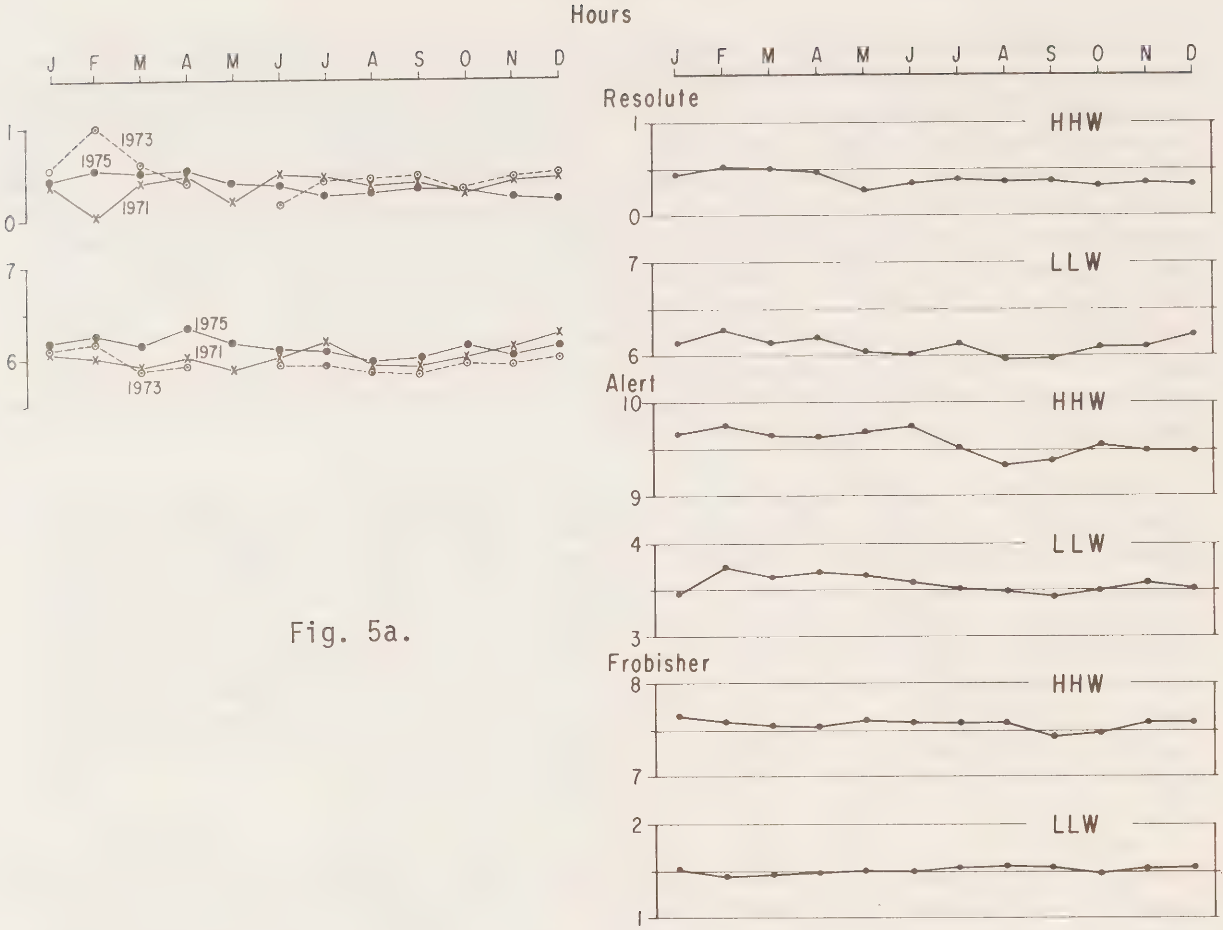

Fig. 5a.

Fig. 5. Monthly sample values of lunitidal intervals. A lunitidal interval is the time elapsed between the lunar transit in Greenwich and the time of local occurrence of high or low water. HHW and LLW denote higher high water and lower low water; during the course of one day approximately two high and low waters occur. Normally one of the high waters is higher than the other and one of the low waters is lower; these are the ones selected to compute the indicated lunitidal intervals. The diagram is divided into two panels: the left panel shows the actual sample value and the right panel shows the average value for the month; if only one year is available, only the right panel is shown. (a) Sample values for Resolute, Alert and Frobisher. (b) For Rae Point, Lake Harbour and Coral Harbour. (c) For Churchill, Cambridge Bay and Cape Parry. (d) For Tuktoyaktuk.

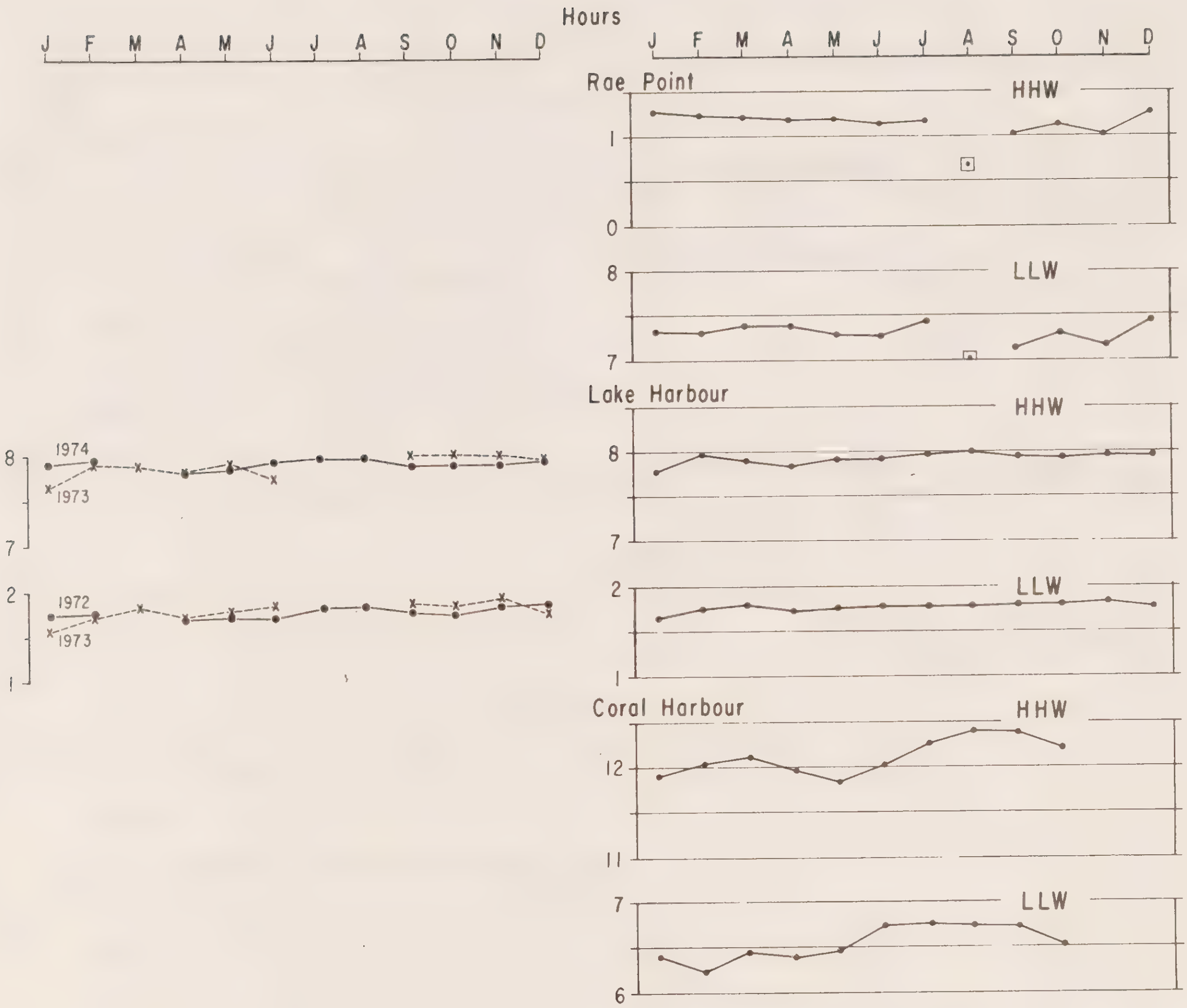
Hours
J F M A M J J A S O N D
Rae Point
HHW
LLW
Lake Harbour
Coral Harbour
1974
1973
1972

Fig. 5b.

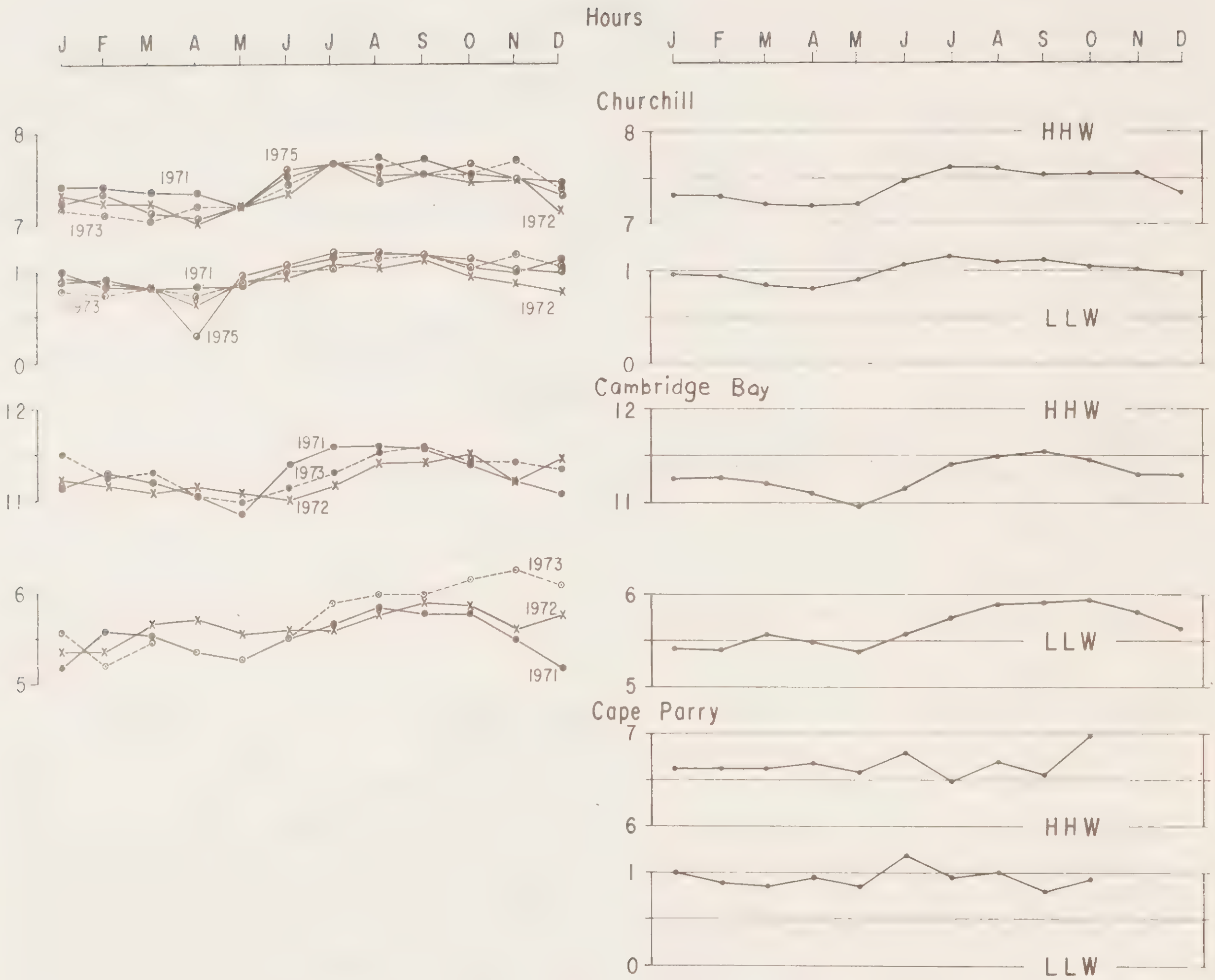
Hours
J F M A M J J A S O N D
Churchill
HHW
LLW
Cambridge Bay
HHW
LLW
Cape Parry
HHW
LLW
1971
1972
1973
1975

Fig. 5c.

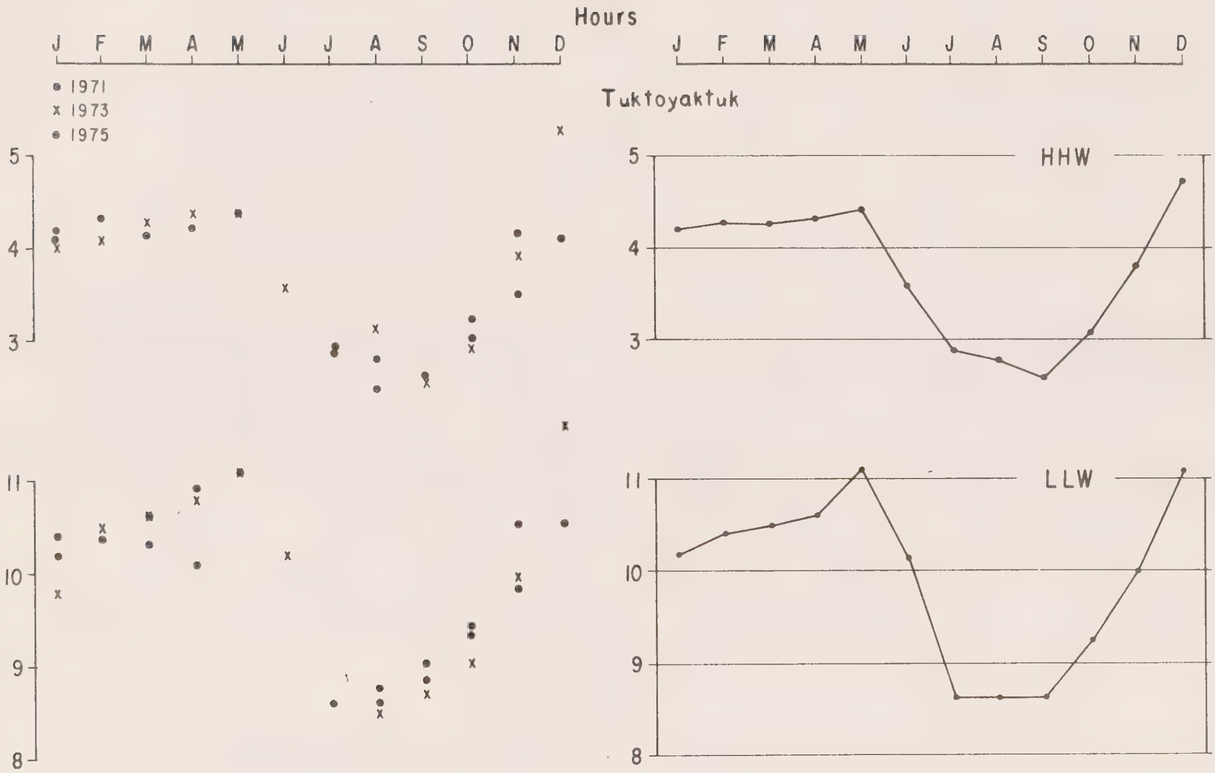
Hours
J F M A M J J A S O N D
• 1971
x 1973
• 1975
5
4
3
11
10
9
8
Tuktoyaktuk
HHW
LLW

Fig. 5d.

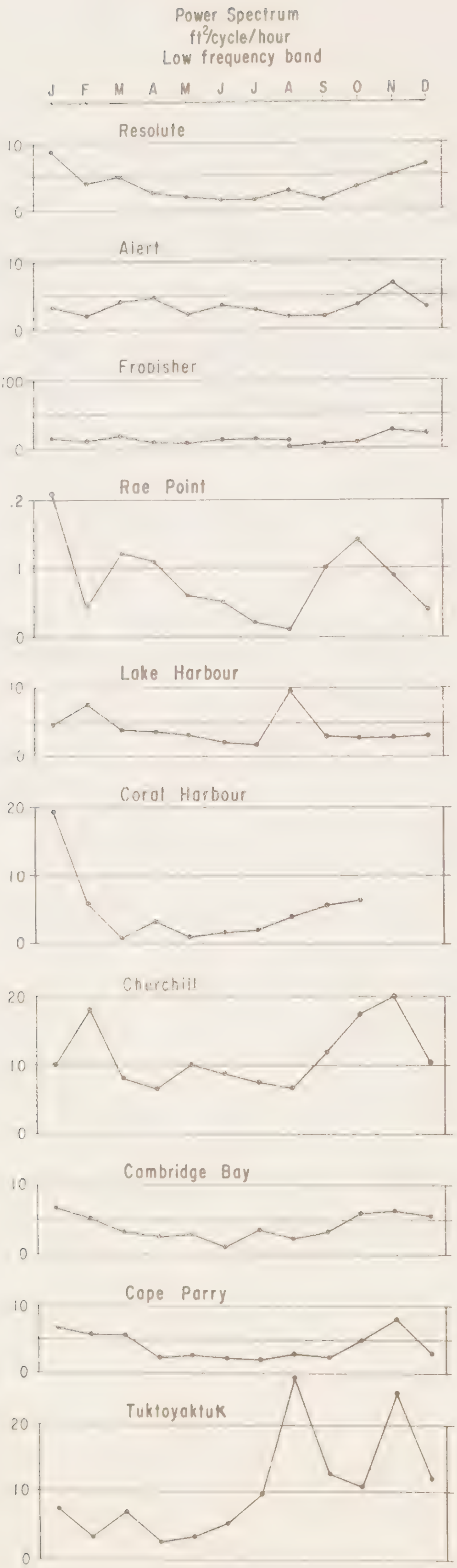

Fig. 6. Monthly sampled values of the power spectrum of the observed water level in the low frequency band (frequencies lower than 1 cycle/24 hours). Tides contribute little in this frequency; weather disturbances and oceanic processes do.

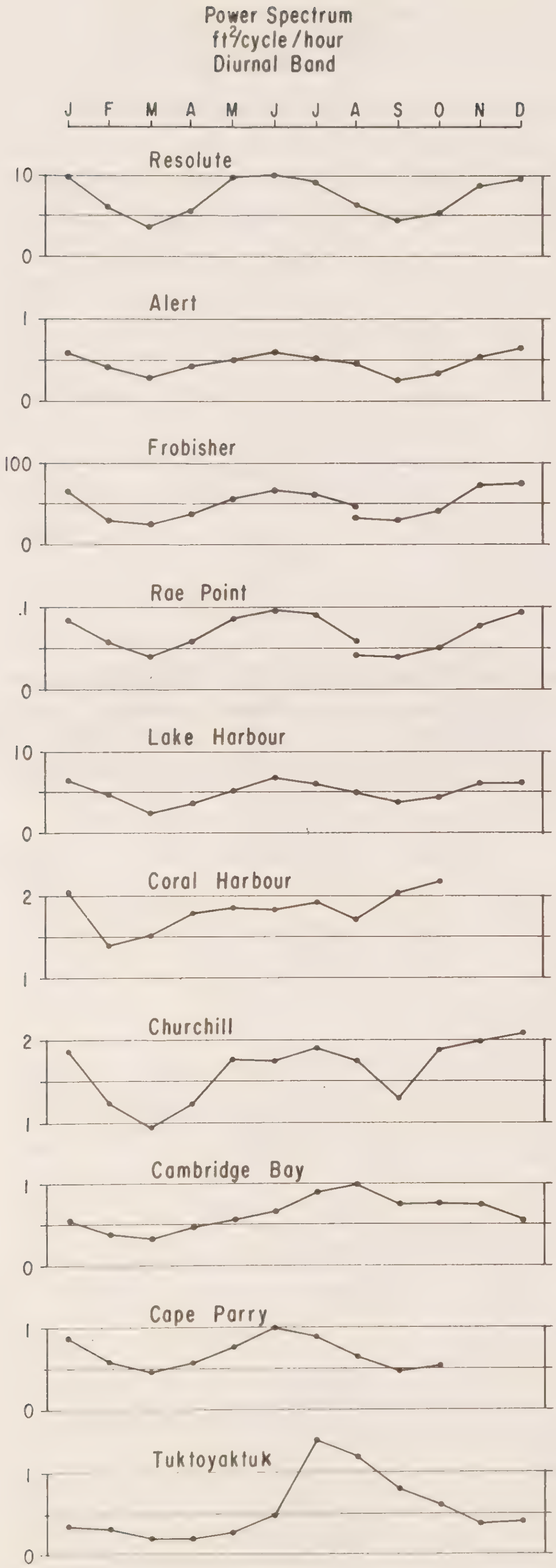

Fig. 7. Monthly sampled values of the power spectrum of the observed water level in the diurnal frequency band (frequencies centered around 1 cycle/24 hours). The tide contributes mainly to this band along with some weather events.

Fig. 8. Monthly sampled values of the power spectrum of the observed water level in the semidiurnal frequency band (frequencies centered around 1 cycle/12 hours) and monthly sample values of the mean range (highly correlated with this band of the power spectrum for tides with a predominantly semidiurnal character).

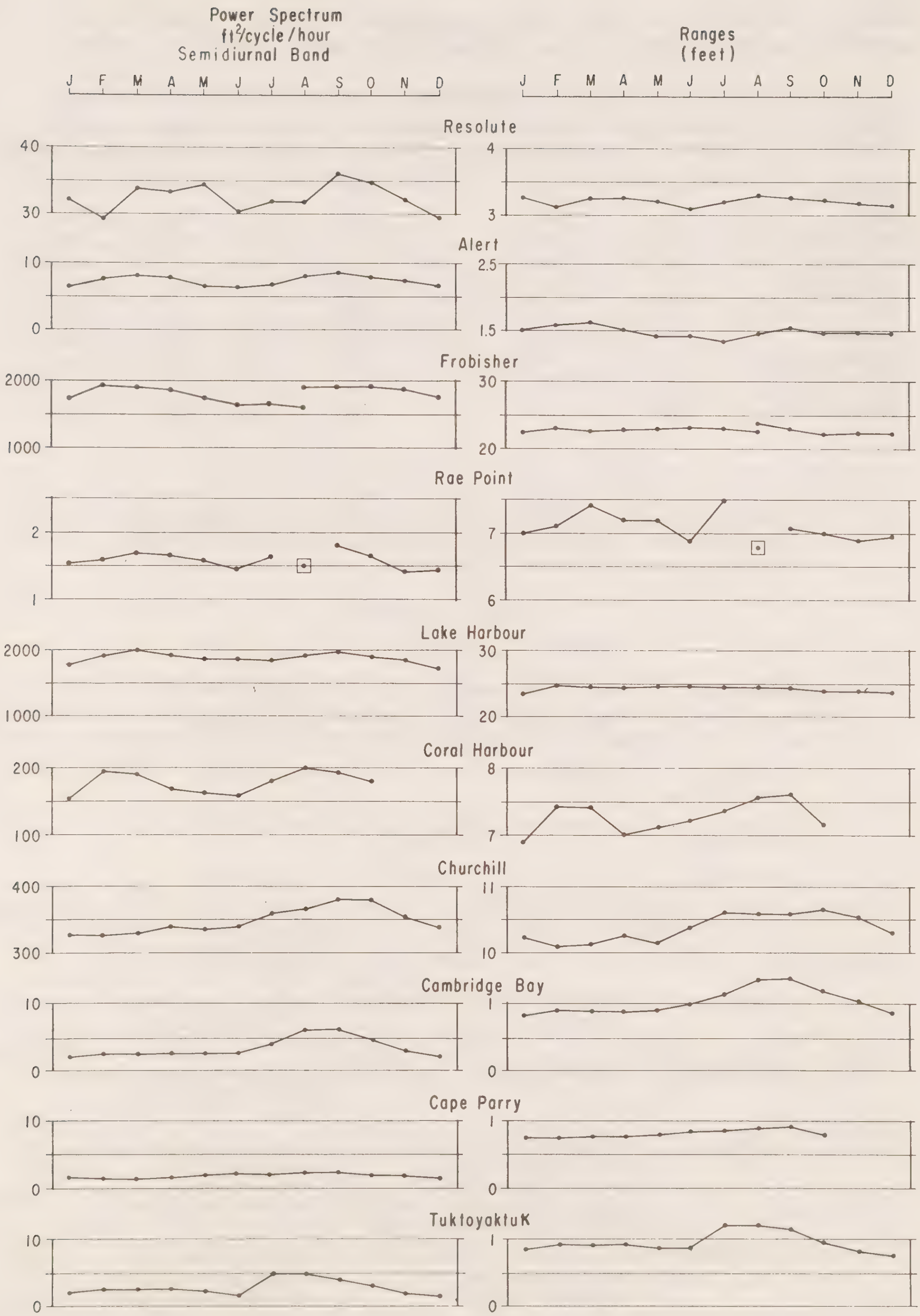
Power Spectrum
ft²/cycle/hour
Semidiurnal Band
Ranges
(feet)
J F M A M J J A S O N D
Resolute
Alert
Frobisher
Rae Point
Lake Harbour
Coral Harbour
Churchill
Cambridge Bay
Cape Parry
Tuktoyaktuk
40
30
4
3
10
0
2.5
1.5
2000
1000
30
20
2
1
7
6
200
100
8
400
300
11

Table 4. Check list of the criteria satisfied (or not) to confirm the modification of the tide by the existence (or absence) of an ice-cover.

Station	Admittance	Lunitidal Intervals	Power Spectrum Band 0	Power Spectrum Band 1	Power Spectrum Band 2	Range	Final Conclusion
Resolute	No	No	?	No	No	No	No
Alert	No	No	?	No	No	No	No
Frobisher	?	No	?	No	No	No	No
Rae Point	?	No	?	No	No	?	No
Lake Harbour	?	No	?	No	No	No	No
Coral Harbour	?	Yes	?	Yes	?	?	Yes
Churchill	?	Yes	?	Yes	Yes	Yes	Yes
Cambridge Bay	?	Yes	?	Yes	Yes	Yes	Yes
Cape Parry	?	No	?	No	?	?	No ?
Tuktoyaktuk	Yes	Yes	?	Yes	Yes	Yes	Yes

Table 5. Arctic stations whose tidal records were searched for a variability induced by the formation and breakup of an ice cover (from Godin and Barber 1980).

Station	Sets of Observations Utilized	Variability
Resolute	1971; 1973 (May missing); 1975	Not detectable
Alert	1971; Jan.-Mar., Sept.-Dec. 1972; Jan.-Jan., Sept.-Nov. 1974	Not detectable
Frobisher (submerged gauge)	Aug. 2976 - Sept. 1977	Not detectable
Rae Point (submerged gauge)	Aug. 1975 - Aug. 1976	Not detectable
Lake Harbour	1972 (Mar. missing); 1973 (Jul. and Aug. missing); 1974	Not detectable
Coral Harbour	Jan.-Oct. 1972	Increased ranges and tide *later* during open water
Churchill	1971; 1972; 1973; 1974 (Nov.-Dec. missing); 1975	Increased ranges and tide *later* during open water
Cambridge Bay	1971; 1972; 1973	Increased ranges and tide *later* during open water
Cape Parry	Jan.-Oct. 1971; Jan.-Sept., Nov.-Dec. 1973; Jan.-Apr., Jul.-Sept. 1975 (data inadequate to calculate the lunitidal intervals for Nov.-Dec.)	Slight increase in ranges during open water; no noticeable difference in the time of arrival of the tide
Tuktoyaktuk	Jan.-Apr., Jul.-Dec. 1971; Jan.-June, Aug.-Dec. 1973; Jan.-May, Jul.-Nov. 1975	Marked irregularities, ranges larger and tide *earlier* during open water

CONCLUSIONS

Table 4 indicates that whatever technique is used tends to corroborate the other, or at least not to contradict the other. So what appears at first as a simple problem required a fair amount of investigation and calculation, which lead to somewhat firm if not definitive conclusions.

If we now pause and try to search for the reasons for such an apparently erratic response of the tide to the ice stress we realize that those stations which do not exhibit a seasonal cycle linked to that of the ice are stations which lie along the ocean or are connected to it by deep channels. In Hudson Bay, for instance, Lake Harbour in Hudson Strait is unaffected while Coral Harbour and Churchill which occupy deep recesses inside Hudson Bay do exhibit larger and *later* tides during the open water season. Similarly Cape Parry and Tuktoyaktuk are in the same portion of the ocean but Tuktoyaktuk lies behind extensive shallows.

It appears therefore that a seasonal change in the character of the tide in the Canadian arctic is a function of geography and does not affect the stations lying around the perimeter of the ocean or connected to it by deep channels.

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REFERENCES

Godin, G. 1977. The analysis of tidal records collected on water bodies of the earth. Ann. Geophys., t. 33, fasc. 1/2: 167-170.

1980. Cotidal charts for Canada. Mar. Sci. Inform. Directorate, MS Rep. Ser. 55: 91 p. (In press).

Godin, G., and F. G. Barber. 1980. Variability of the tide at some sites in the Canadian arctic. Arctic 33(1): 30-37.

Henry, R. F., and M. G. G. Foreman. 1977. Numerical model studies of semi-diurnal tides in the southern Beaufort Sea. Pac. Mar. Sci. Rep. 77-11, Inst. Ocean. Sci.: 71 p.

Laktionov, A. F. 1960. The problem of the effect of ice on tidal phenomena. Problemy Arktiki I Antarktiki. 5: 53-58. (From a translation by M. Slessors, U.S. Naval Oceanogr. Office, 1963: 11 p.

Murty, T. S., and R. J. Polavarapu. 1978. Influence of an ice layer in the propagation of long waves. Mar. Geodesy 2(2): 99-125.

Zetler, B., D. E. Cartwright, and W. Munk. 1970. Tidal constants derived from response admittances. Int. Symp. Earth Tides, Obs. Royal de Belgique, Brussels: 175-178.

Zubov, N. N. 1943. Arctic ice. Trans. U.S. Navy Electronics Lab.: 491 p.

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